ISSN 1047-3289 J. Air Waste Manage. Assoc. 40: 1012-1017 (1990)

Impact of "Designated Smoking Area" Policy on Nicotine Vapor and Particle Concentrations in a Modern Office Building

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A series of measurements of nicotine vapor and particle concentrations were carried out in a modern office building. The measurement program was designed to document the impact of the new smoking policy (e.g. smoking restricted to two specific areas) on air quality in various parts of the building.

Measurements at over 30 locations examined areas where smoking was restricted, where smoking was permitted, and where an air handler shared the load of a designated smoking area. These measurements were taken at the same locations before and after the policy was implemented.

The measurement results indicated that:

- After the policy was implemented, general employee exposure to nicotine vapor (as a surrogate for all environmental tobacco smoke) was reduced by about 98 percent on most floors. Other patterns related to spillover from designated smoking areas and changes in the designated smoking areas themselves are described in the paper.
- Substantial reductions in exposure to nicotine vapor were found even for those general office areas which had the highest concentrations after the policy was implemented.

A large corporation implemented a new smoking policy in its headquarters in January 1988. This new policy restricted smoking to designated areas of the 32nd floor snack bar and the eastern part of the cafeteria only.

Implications

The study reported in this article demonstrates that:

- It is possible to make objective measurements of nicotine vapor in an office setting using inexpensive passive sampling devices.
- It is possible to demonstrate the effectiveness of a change in smoking policy using before and after monitoring.
- Use of a designated smoking area can significantly (90–98 percent) reduce office exposure to nicotine vapor and hence other smoking vapors.
- With common air handlers typical of modern office buildings, adjacent office spaces can receive spillover of vapors from a designated smoking area.

In order to document the air quality impact of this change in policy, measurements were conducted on four floors of the headquarters before and after the policy went into effect. Nicotine vapor measurements documented the specific changes in air quality due to tobacco smoke. Additional measurements of inhaled particle load at selected locations linked particle and nicotine vapor concentrations (to assess changes in visible smoke as well).

The general objectives were to:

- Define the initial concentrations of nicotine vapor and inhalable particles (as a measure of baseline air quality).
- Document the change in air quality on a typical floor where smoking would no longer be allowed.
- Document the change in air quality in the 32nd floor snack bar (where smoking was allowed) as well as any "spill over" to adjacent office areas.
- Document the change in air quality on the 31st floor, which shares the air handler with the 32nd floor, to see if smoking impact was "imported" to this non-smoking area.
- Document the changes in air quality of the different areas of the cafeteria.

Methods

Sampling Devices

Two types of sampling devices were used in this study to capture the nicotine vapors from the air—passive and active. They both operated with the same principle of stabilizing the nicotine on a filter treated with sodium bisulfate. The passive devices utilized diffusion across a wind screen membrane to deposit the vapors. The active devices used a pump to draw room air through an identically treated filter at the rate of about 1.7 liters per minute. This active sampler was also equipped with a standard teflon coated glass fiber filter to test for inhalable particles at the same time, as explained below.

Passive samplers. The passive samplers consist of a plastic holder, a clip to hold it in place, a teflon-coated glass fiber filter treated with a 4 percent sodium bisulfate solution, and a plastic wind screen (to prevent strong drafts from influencing the sampling). Each filter holder is sealed until sampling begins when the solid lid is replaced by the wind screen. A schematic drawing of a passive sampler assembly appears in Figure 1.

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Each passive sampler was exposed from Monday morning through Friday afternoon to collect a weekly average nicotine concentration. It samples at a rate of about 24 mL/min as determined by chamber studies.[1] The sampling volume is then computed for the exposure interval by multiplying by the rate (24 mL/min) by the number of minutes of exposure.

Active samplers. Active sampling occurred on the Wednesday of each sampling period. The active sampler assembly is a typical occupational health sampling unit equipped with a standard particle filter ahead of a second treated filter to trap the nicotine vapor.[2] The inlet to the filter assembly was a 10-mm nylon cyclone that is designed to allow only the respirable size particles to pass to the filter at a sample rate of 1.7 liters/minute (L/m).

The sample volume for both filter elements is determined by the sample rate which was maintained by battery operated SKC personal sampling pumps (Model 224). These pumps were calibrated at 1.0 and 2.0 L/min before each sampling period. The flow meter reading on each pump was used to adjust the sampling rate to about 1.7 L/m. These flows were checked at two- to three-hour intervals during the intensive sampling days to maintain constant flow. Little adjustment was ever required.

Sampling Locations and Conditions

Phase I of the sampling was conducted in early December 1987, four weeks prior to the implementation of the policy restricting smoking. Phase II sampling occurred in February 1988, after the policy had been in effect for seven weeks.

Site Selection Procedure

The sampling locations were chosen to determine changes in both typical work area exposure and in areas to be most heavily impacted by the new policy. The 32nd floor was selected since smoking would be allowed in the snack bar resulting in an influx of smokers from the rest of the building. The 31st floor was selected since it shares an air handler with the 32nd floor and might share any decreased air quality associated with an increase in smoking on the 32nd floor. The 19th floor was selected as a "typical" floor which would experience only a decrease in its smoking population. The cafeteria was selected since it would be divided into smoking and non-smoking areas.

Each of the office floors is primarily open with cubicles defining work space. Only one "private" office was sampled (location #22 below). The specific sample locations on these office floors were determined by generating random number grid coordinates for about 2,000 sq-ft sections of each floor. This step resulted in different random locations for possible sampling on each floor. This pattern was then compared to the information on office cubicles occupied by smokers (S) and non-smokers (NS) or vacant (V), as supplied by floor managers. Possible sample locations were then shifted one or two cubicles away to assure a mix of S, NS and V samples from each floor. The snack bar on the 32nd floor received three samplers, since it would experience the largest potential change and would warrant the greatest attention.

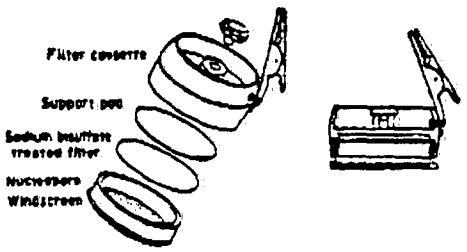

Figure 1. Diagram of passive monitor to sample nicotine in the air.

Table I. Sample locations and types of exposure (sites with "a" designate active sampling also).

Floor	Location	Type of Exposure
32nd	1	Public-snack bar, smoking (Phase II)
	2	Public-snack bar, smoking (Phase II)
	3[a]	Public-snack bar, smoking (Phase II)
	4	Non-smoker
	5	Non-smoker
	6[a]	Vacant (Phase I), non-smoker (Phase II)
	7[a]	Smoker (Phase I), vacant (Phase II)
	8	Smoker
	9	Non-smoker
31st	10[a]	Smoker
	11	Common terminal area
	12	Non-smoker
	13	Vacant (Phase I), non-smoker (Phase II)
	14	Public-on a divider
	15[a]	Non-smoker
	16	Damaged (Phase I), non-smoker (Phase II)
	17	Vacant
19th	18	Non-smoker
	19	Non-smoker
	20	Non-smoker
	21	Damaged (Phase I), non-smoker (Phase II)
	22[a]	Smoker (enclosed office)
	23	Smoker
	24[a]	Non-smoker
	25	Damaged (Phase I), non-smoker (Phase II)
Cafeteria	26[a]	Public, no smoking (Phase II)
	27	Public, no smoking (Phase II)
	28[a]	Public, no smoking (Phase II)
	29	Public, no smoking (Phase II)
	30	Public, no smoking (Phase II)
	31	Public, no smoking (Phase II)
	32[a]	Public, only Phase II—smoking area

At the time the six locations for the Phase I cafeteria sampling were selected, there was no firm idea as to which areas would be designated smoking and which non-smoking. Hence, a relatively even distribution of locations (#26 through #31) was laid out in the western portion of the cafeteria. Ultimately, the eastern half of the cafeteria was designated the smoking area. For the Phase II sampling, an additional sample location (#32) in that area was set up for the active sampling.

The final 32 sampling locations were refined during the setup for Phase I sampling. Usually a passive sampler was clipped to the center of a desk lamp or at the end of a lamp to avoid being directly over an ash tray. For the open areas, the passive samplers were attached to the drop ceiling supports in the snack bar and the light fixtures of the cafeteria.

During each phase of sampling, active samples were gathered at nine to ten locations. These active sites were also chosen arbitrarily to achieve a mix of S, NS and V sites throughout the three office floors. Two sites in the western half of the cafeteria were also selected.

Table I lists the final mix of sampling locations and indicates the type of exposure. Figures 2 and 3 show the locations of these sample points on floor plans for the two floors experiencing the greatest changes.

For each sampling location, a log sheet was completed which noted the actual installation point, indications of smoking in the area, time of placement and removal, and comments. Each site was revisited at least once during the Wednesday intensive sampling and on removal. These site-specific records assisted in interpreting the nature of the exposure or unique conditions at each location.

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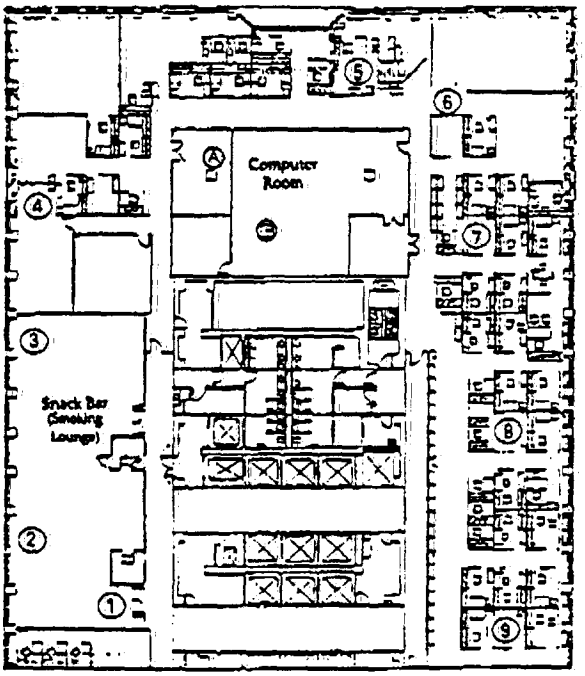

Figure 2. Map of sampling locations on 32nd floor.

Sample Analysis

The nicotine vapor collected on both the passive and active filters was analyzed by the procedures described by Hammond and Leaderer.[1,2] Briefly, the nicotine was desorbed from the filters with water. The pH was adjusted with sodium hydroxide. The nicotine was concentrated by liquid/liquid extraction into ammoniated heptane. A small amount of the heptane solution was injected into a gas chromatograph which was equipped with a nitrogen selective detector.

The detection limit for the method depends on the nicotine levels of field blanks (filters shipped to the study area, opened briefly on site, and returned to the laboratory just like the actual samples) which must be subtracted from the levels obtained on actual samples. For this study the passive blanks were at or below 0.01 μg. The final passive detection limit was determined to be 0.03 μg of nicotine. For the active samples the detection limit was determined to be 0.2 μg of nicotine (partly because of a different range for analysis).

The particle loading is determined from the front filter of the active filter assembly. It is pre-weighed at the laboratory before being sent to the field, then re-weighed after sampling. The difference is then reported as the particle loading. The reliable minimum detection limit is about 20 μg of particle and all values below that limit are reported as not detected (ND) with the actual value shown in parentheses.

Results and Observations

Results

Tables II and III present a summary of all nicotine vapor analyses during the study. The office results are grouped by floor with a separate sub-grouping of public area (snack bar and cafeteria) samples for both before and after conditions. Reference should be made to Table I and Figures 2 and 3 for actual cubicles and general locations on each floor.

It should be noted that these passive sampling results are computed from a 45-hour exposure period assuming that, on the average, the sources of nicotine vapor and the people exposed are in the area about 9 hours a day, even though the passive sampling proceeds for 24 hours a day. This assumption may be inaccurate for some locations but is a best estimate that also allows comparisons with other work week studies by using a consistant data reduction approach.[3] In one instance, at site #10, the smoker was away from the office for three days during Phase I. We have adjusted the nicotine level at that location to reflect 18 hours of "exposure," not 45.

The nicotine values from the active samplers for each sampling phase are presented in Table IV. Columns allow comparisons of the intensive sampling on Wednesday with the "work week" average. This grouping shows whether the Wednesday samples were "typical" (i.e. Wednesday readings close to average week values) as indicated by nicotine levels, and most are typical.

Table V allows comparison of the before and after active samples for both nicotine and particle values.

Observations

Before conditions. Nicotine vapor concentrations at nonsmoking desks in the general office areas were about 2 $\mu g/m^3$ in December 1987. Nicotine concentrations in the snack bar were about 11 $\mu g/m^3$ or just over 5 times NS desks, while those in the cafeteria were about 3.4 $\mu g/m^3$ or 1.5–2 times NS desks.

The range of average smoker desk concentrations on each floor were highly variable (Table III), and ranged from 3 to 33 $\mu g/m^3$ or about 2 to 15 times that at the NS desks.

In general, the "vacant" desk areas had about the same nicotine vapor concentration in December 1987 as the nonsmoker areas with the exception that the vacant space at Site #17 had a value of 6.7 $\mu g/m^3$. Perhaps there was a nearby smoker or a smoker borrowed the cubicle to work for several hours that week.

Unfortunately four of the Phase I particulate filters were lost so that adequate baseline information is missing. Those data that are available show low particulate levels at the NS and V desks, as would be expected, and higher values at one

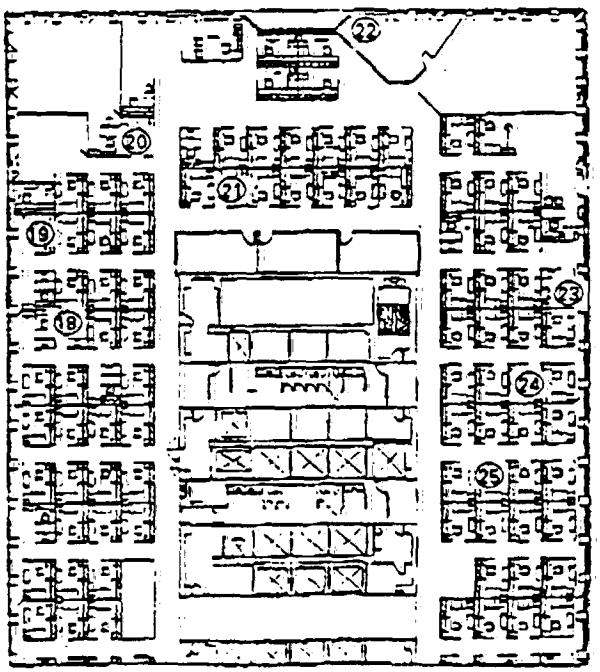

Figure 3. Map of sampling locations on 19th floor.

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Table IIa. Nicotine concentrations ($\mu g/m^3$) in offices (+ to left indicates Wed. intensive sampling).

Offices

32nd Floor

Loc. #	Type SNV	Before	After	Change
4	N	1.8	0.7	−1.1
5	N	2.2	0.3	−1.9
+6	V	1.6	0.1	−1.5
+7	S	33.3	0.4	−32.9
8	S	14.7	0.4	−14.3
9	N	1.9	0.1	−1.8
	Area Ave. =	9.3	0.3	−9.0

31st Floor

Loc. #	Type SNV	Before	After	Change
+10	S	3.4	0.7	−2.7
11	V	3.1	0.4	−2.7
12	N	1.8	0.4	−1.4
13	N	2.1	0.3	−1.8
14	S	4.6	0.3	−4.3
+15	N	1.9	0.3	−1.6
17	V	6.7	0.2	−6.5
16	N	damaged	0.2	
	Area Ave. =	3.4	0.4	−3.0

19th Floor

Loc. #	Type SNV	Before	After	Change
+22	S	4.3	0.2	−4.1
18	N	0.9	0.0	−0.9
19	N	1.6	0.1	−1.5
20	N	5.3	0.1	−5.2
23	S	3.9	0.0	−3.9
+24	N	1.0	0.1	−0.9
21	N	damaged	0.0	
25	N	damaged	0.0	
	Area Ave. =	2.8	0.1	−2.7

Table IIb. Nicotine concentrations ($\mu g/m^3$) in snack bar & cafeteria (+ to left indicates Wed. intensive sampling).

Public areas

Snack Bar

Loc. #	Before	After	Change
1	10.4	36.6	26.2
2	13.2	41.0	27.8
+3	10.2	178.7	168.5
Area Ave. =	11.3	85.4	+74.1

Cafeteria

Loc. #	Before	After	Change
+26	5.0	2.4	−2.6
27	5.8	3.5	−2.3
+28	6.7	4.1	−2.6
29	5.5	3.3	−2.2
30	2.4	6.6	4.2
31	1.8	11.6	9.8
Area Ave. =	4.5	5.3	+0.8

smoker's desk. The western part of the cafeteria had quite low particulate levels during Phase I measurements.

After conditions and comparisons. Overall air quality, as measured by nicotine concentrations improved dramatically in the office areas as a result of the new policy restricting smoking. The average non-smoker desk values were 0.1–0.3 $\mu g/m^3$ during the February 1988 measurements compared to 2.0 $\mu g/m^3$ earlier. The greatest improvement in overall air quality (95+ percent reduction in ETS exposure) was on the 19th floor, due to the prohibition of all smoking without any common air handling with a smoking location.

However, there is evidence of some tobacco smoke "spillover" into non-smoking areas on the 31st and 32nd floors, which had reductions in ETS exposure of only 84 percent and 80 percent respectively. The highest levels at non-smoker desks were on the 32nd floor. The highest level at a 32nd floor cubicle was at Site #4 (0.7 $\mu g/m^3$) which receives fumes from the hallway outside the snack bar smoking area.

(There is also some evidence of "off gassing" of tobacco smoke vapors from the clothes of smokers or from the porous fabric on the divider walls. This observation comes from the general pattern that most smoker cubicles exhibit nicotine values which are slightly higher than non-smoker values.)

The 32nd floor snack bar experienced the most significant decrease in air quality in the building. The February 1988 average nicotine vapor concentration (85.4 $\mu g/m^3$) was 7.6 times higher than the already high December 1987 levels. These concentrations were highest at the eastern end of the "designated smoking area." (Site #3), perhaps due to ventilation changes made by the maintenance staff to encourage the air flow in that direction.

The highest nicotine vapor and particulate readings were at Site #3 in the snack bar. These levels were at least 1,800 times higher than the average values in the non-smoking office areas.

The cafeteria—in spite of its higher ceilings and larger air volume—showed, at best, only slight improvement in air quality at four NS locations (#26–#29) and decreased air quality at two locations (#30 and #31). The latter non-smoking locations were nearest the newly designated smoking area and were three to ten times higher in February 1988 than in December 1987. Due to the dramatic change in these two cafeteria nicotine levels, the overall western cafeteria (NS area) readings are 16 percent higher in February 1988 compared to December 1987. The second highest nicotine vapor (and particle readings) measured were in the newly designated smoking area at the eastern end of the cafeteria. Four of the six western cafeteria locations did show improvement in nicotine vapor levels in February 1988 compared to December 1987 but the reduction was only about 50 percent compared to 80–98 percent on the working floors.

[Note: Since this original work was performed in 1987 and early 1988, two subsequent studies have been performed in the same building on the "snack bar" floor (32nd) using the same sampling and analytical methods. One study in December 1988 focused on levels in and near the computer room on the 32nd floor that had a separate air conditioner system but had a common above-ceiling plenum with the snack bar/smoking lounge. (Figure 2 locations A and B were part of that study.) At that time construction was underway to build an isolated smoking lounge to the west of the snack bar/smoking lounge by extending new walls from slab to slab, thus eliminating the common above ceiling plenum, and by providing a totally separate air handling system that accomplishes 20 air changes per hour.

In the December 1988 measurements around the computer rooms, spillover levels of 14.1 $\mu g/m^3$ (at A) and 59.0 $\mu g/m^3$ (above the drop ceiling at B) indicated that spillover ETS was encroaching on the computer room. Levels in the computer room were only about 1.1 $\mu g/m^3$.

In September 1989, measurements were carried out in the new isolated smoking lounge and at the point of highest February 1988 readings in the snack bar (No. 3 in Figure 2—178.7 $\mu g/m^3$). These measurements indicated that the snack bar location had decreased to 0.6 $\mu g/m^3$ of nicotine vapor. The new, well-ventilated (20 air changes per hour) and isolated smoking lounge had nicotine vapor levels of 70–77 $\mu g/m^3$.

Along with the above quantitative improvement in the air quality for the snack bar, there was one qualitative observation from the manager of the computer room on the same floor. He reported "a significant decrease in the number of disk crashes" (a problem that had prompted the December

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Table III. Summary of nicotine vapor concentrations averaged by type of exposure on each floor.

Exposure	Floor	Ave. concn. ($\mu g/m^3$) Before	After	Ratio after/before
Smokers	33nd	24.0	0.4	0.02
	31st	4.0	0.5	0.13
	19th	4.1	0.1	0.02
Non-smoker	32nd	2.0	0.4	0.19
	31st	1.9	0.3	0.16
	19th	2.2	0.1	0.02
Vacant	32nd	1.6	0.1	0.06
	31st	4.9	0.3	0.06

1988 measurements) and "significantly fewer computer headaches" since the new isolated smoking lounge had gone into use.]

Conclusions

In general, this environmental tobacco smoke measurement program achieved its objectives and documented various changes in air quality associated with the new policy restricting smoking at one company's headquarters. One can conclude from these measurements that:

- After the policy was implemented, general employee exposure to nicotine vapor (as surrogate for all environmental tobacco smoke) was reduced by over 95 percent on most floors (like the 19th floor). All office areas were reduced to less than 1 $\mu g/m^3$ of nicotine vapor.
- Even the highest concentrations in the general office areas (those adjacent to the designated smoking areas) in February 1988 are much lower than they had been in December 1987.
- While air quality in the work areas of the 31st and 32nd floors improved, the improvement was not as great as on floors that did not share an air handler with a floor having a smoking area. The average level on the 31st floor was four times that on the 19th floor.
- There is evidence that environmental tobacco smoke vapors are spilling over into the office areas of the 32nd floor, probably through open doors and shared overhead plenums.
- Under the new policy the 32nd floor snack bar was measurably quite contaminated with environmental tobacco smoke with worst case levels at least 1,800 times higher than the typical February 1988 office area.
- The cafeteria air quality was, in general, poorer in aver-

Table IV. Comparison of weekly average nicotine vapor concentrations with Wednesday "active" samples (units = $\mu g/m^3$).

Location #	Phase	Wednesday active	Weekly average[a]	Comments
Offices				
6	I	0.0	1.6	
	II	0.2	0.1	Wed. appears typical
7	I	18.7	33.3	Wed. appears typical
	II	0.0	0.3	Wed. appears typical
10	I	0.0	3.4	Smoker out M–W
	II	0.2	0.7	Wed. appears typical
22	I	0.5	4.3	Smoker in <2.5 hours on Wed.
	II	0.1	0.2	Wed. appears typical
15	I	0.1	1.9	
	II	0.0	0.3	Wed. appears typical
24	I	0.7	1.0	Wed. appears typical
	II	0.0	0.1	Wed. appears typical
Snack bar				
3	I	7.0	10.2	Wed. appears typical
	II	141.0	179.0	Wed. appears typical
Cafeteria				
26	I	0.4	5.0	Wed. much LOWER
	II	0.3	2.4	Wed. appears LOWER
28	I	1.2	6.7	
	II	1.0	4.1	Wed. appears LOWER

[a] Day only—assumed 45 hr. exposure.

Table V. Summary of Wednesday intensive sampling (units = $\mu g/m^3$).

Loc. #	Type SNV	Nicotine Vapor Before	After	Change	Particulate Load Before	After
Office						
7	S	18.7	0.0	−18.7	lost	ND (12)
6	N	0.0	0.2	0.2	20	ND (0)
10	S → V	0.0	0.2	0.2	270	35
15	N	0.1	0.0	−0.1	45	ND (0)
22	S → V	0.5	0.1	−0.4	lost	ND (12)
24	N	0.7	0.0	−0.7	lost	ND (10)
Snack bar						
3		7.0	140.8	133.8	lost	527
Cafeteria						
26		0.4	0.3	−0.1	ND (2)	32
28		1.2	1.0	−0.2	ND (0)	27
32			30.1			102

Notes: lost—sample lost by error.
ND—below detection limit of 20 $\mu g/m^3$.

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age nicotine vapor levels than it was before the new policy restricting smoking went into effect.

- Based on subsequent 1989 measurements, an isolated smoking lounge quantitatively and qualitatively improved conditions elsewhere on the 32nd floor.

Acknowledgment

This work was performed under subcontract to AeroVironment, Inc. of Monrovia, California and managed by Michael Chan, CCM. The authors appreciate receiving permission from AeroVironment and its client for the publication of these data. The client requested that its name be withheld from this report.

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This paper was submitted for peer review on April 24, 1989. The revised manuscript was received April 11, 1990.

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